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Pressure Measurements in Cryogenic Systems

by [redacted]

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PRESSURE MEASUREMENTS IN CRYOGENIC SYSTEMS

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- ABSTRACT -

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Some of the problems associated with pressure measurements in cryogenic systems are presented. These problems can in many cases be eliminated by using pressure transducers at cryogenic temperatures. Tests were conducted at the Cryogenic Engineering Laboratory on a few types of commercially available transducers to determine their suitability for operation at temperatures down to 20°K. The results of these tests indicate that accurate pressure measurements can be made at cryogenic temperatures by using some of these types if their calibration is checked each time they are cooled down.

- INTRODUCTION -

Pressure measurements in cryogenic systems have, for years, been made by simply running gage lines from the point where the pressure measurement is desired to some convenient location at ambient temperature and attaching a suitable pressure measuring device. This system works quite well for most applications; however, there are disadvantages to this straightforward approach that may introduce problems in many systems. The two most important are reduced frequency response and thermal oscillations. In addition, heat leak and fatigue failure of gage lines could become significant in some applications. Such problems associated with pressure measurement at cryogenic temperatures could be eliminated by installing pressure transducers at the measurement point, thereby doing away with gage lines. Data gathered by the author indicate that existing pressure transducers can be used at temperatures down to the liquid hydrogen range, provided that the correct transducer for each application is selected, properly calibrated and installed, and its limitations clearly understood.

As cryogenic systems become more sophisticated, especially those related to the aerospace field, the requirement for good frequency response in pressure measurement becomes more demanding. With many pressure transducer installations the limiting factor in frequency response is the connecting piping.(1) This is especially true if the lines are long and of small diameter, as they often are to minimize heat leak in cryogenic applications. The best frequency response for a given type of transducer is, of course, obtained when a flush diaphragm instrument is installed directly into the system. The importance of this consideration in the application of pressure transducers to cryogenic systems is obvious.

Gage lines that run from some relatively "high temperature" location into a cryogenic liquid can give rise to pulsations unless care is taken to fix the liquid-vapor interface in the line. This phenomenon is caused when liquid is suddenly forced into a gage line to a point where the temperature

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is above the saturation temperature of the liquid. The resultant pressure rise forces the liquid back in the line, causing a drop in pressure which again allows the liquid to move into the high temperature region, starting a new cycle. Instances have occurred when this process has caused pressure gages to oscillate rapidly between zero and full scale, making reading of the gage impossible.[2] This problem is especially bad with liquid hydrogen and liquid helium because of their low viscosity and low latent heat of vaporization. Damping can be introduced in the gage line, but this, of course, further limits the frequency response of the system. Careful placement of the gage line at the point where it enters the cryogenic fluid can eliminate pulsations under quiescent conditions, but does not necessarily insure their elimination if pressure surges occur, as might happen during filling or emptying a dewar.

- EXPERIMENTAL METHOD -

A program was set up at CEL to try to determine the suitability of commercially available pressure transducers for operation at cryogenic temperatures, especially in the liquid hydrogen range.

The experimental procedure adopted for this program consists of calibrating the test instrument at ambient, liquid nitrogen, and liquid hydrogen temperatures, thermal cycling the instrument between 70° F and liquid nitrogen temperature not less than fifty times at a constant pressure, and then recalibrating at the three temperatures. For each set of calibrations the instrument is zeroed at ambient temperature (where this is appropriate), and this setting is not changed during the low temperature calibrations unless the zero shift is too great. The instrument is cooled slowly at zero pressure and the calibration runs are not attempted until the instrument appears to be at thermal equilibrium as indicated by both stable temperature measurements and stable zero pressure output.

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- EXPERIMENTAL SET-UP -

Figure I is a schematic diagram of the cryostat and associated plumbing assembled for this program. The instruments are in a helium atmosphere which allows the experimental volume to be opened with no safety hazard, even when the cryostat is at liquid hydrogen temperature. The instruments being tested are pressurized with helium gas, both for safety reasons, and to avoid any problems which might arise due to condensation in the instrument or the pressurizing line.

Pressure measurements are made with 0.25% test gages which are calibrated with a precision dead weight tester.

The temperature of the instrument under test is measured with two thermocouples. One, used primarily for monitoring cooldown, is copper versus constantan with an external liquid nitrogen reference. The other is gold-cobalt versus copper referenced to a platinum resistance thermometer mounted near the transducer.

One of the primary uncertainties with the use of pressure transducers at cryogenic temperatures is the effect of thermal cycling on the performance of the instrument. A simple device was constructed to automatically cycle the test instruments between approximately 70°F and liquid nitrogen temperature. The cycling mechanism is controlled by the temperature of a thermocouple attached to the side of the instrument. A time delay built into the timing circuit holds the test instrument in liquid nitrogen for approximately nine minutes after the thermocouple is cooled. After being raised from the liquid nitrogen bath, the instrument is warmed by nitrogen gas maintained at 70°F and circulated by a small fan. With this arrangement, a complete cycle takes approximately twenty minutes, the exact time being dependent upon the size of the test instrument. During cycling the temperature indicated by the thermocouple, the excitation voltage, the output of the test instrument, and the pressure in the system are recorded on a multipoint recorder.

- RESULTS OF TESTS -

The types of transducers tested so far include capacitance, potentiometer, unbonded strain gage, and bonded strain gage.

The capacitance type tested was one in which the deflection of a pressure resisting diaphragm changes the resonant frequency of an oscillator. As would be expected, the instrument was extremely temperature sensitive. So much so, in fact, that it had to be re-zeroed at each temperature before calibration could be attempted.

All of the other instruments tested showed a deviation from their initial room temperature calibration when re-calibrated at liquid nitrogen and liquid hydrogen temperatures. This ranged from 2.7% of initial full scale output for the instrument with the smallest deviation to a maximum of 16% for the instrument with the greatest deviation. These figures include any shift in the calibration which may have occurred during thermal cycling.

The one bonded strain gage type tested (Fig. 2, 2a) exhibited large changes in calibration after thermal cycling, and its zero pressure output after rewarming to room temperature tended to be quite erratic.

Of the two potentiometer types tested, one showed very good performance (Fig. 3, 3a), although it developed some non-linearity at low temperatures after thermal cycling. The other one showed a marked hysteresis at low temperatures (Fig. 4, 4a).

One of the unbonded strain gage types had the smallest error of any tested, and none of the three tested showed any tendency to develop marked non-linearity. However, some models showed large transient errors when they were subjected to severe thermal gradients during the thermal cycling process. The unbonded strain gage types were the most stable with respect to thermal cycling. However, of the three different ones tested, there were three different reactions to the low temperature environment. (Fig. 5, 6, 7).

All of the instruments tested showed a deviation between their initial low temperature calibrations and their final low temperature calibrations. The most stable instruments had a change of approximately 1% of their initial room temperature full scale output.

- CONCLUSIONS -

Judging among the samples included in this series of tests, it appears that the unbonded strain gage will give the most satisfactory results at cryogenic temperatures. With the unbonded strain gage, measurements with an accuracy comparable to that obtainable at room temperature appear possible, if the instrument is used over a reasonable temperature span, and if the calibration is checked each time the instrument is cooled down. However, in a situation where large transient temperature excursions are experienced, as in the cooldown of a transfer line, their use would be questionable because of the possibility of large transient errors.

The potentiometer type also appears to be quite useful. The best of the two tested showed more thermal cycling effects than the unbonded strain gage, but no tendency to produce transient errors during rapid cooling was observed. A calibration check each time the instrument is cooled down would assure the best results.

This study indicates the feasibility of using pressure transducers at cryogenic temperatures, even though many types have not as yet been tested.

References

1) Jon Inskeep, Dynamic Testing of Pressure Transducers - A Progress Report, Jet Propulsion Lab., Calif. Inst. of Technol., Pasadena, Calif. (1961).

2) R. B. Scott, Cryogenic Engineering, D. Van Nostrand Co., Inc. 244 (1959).

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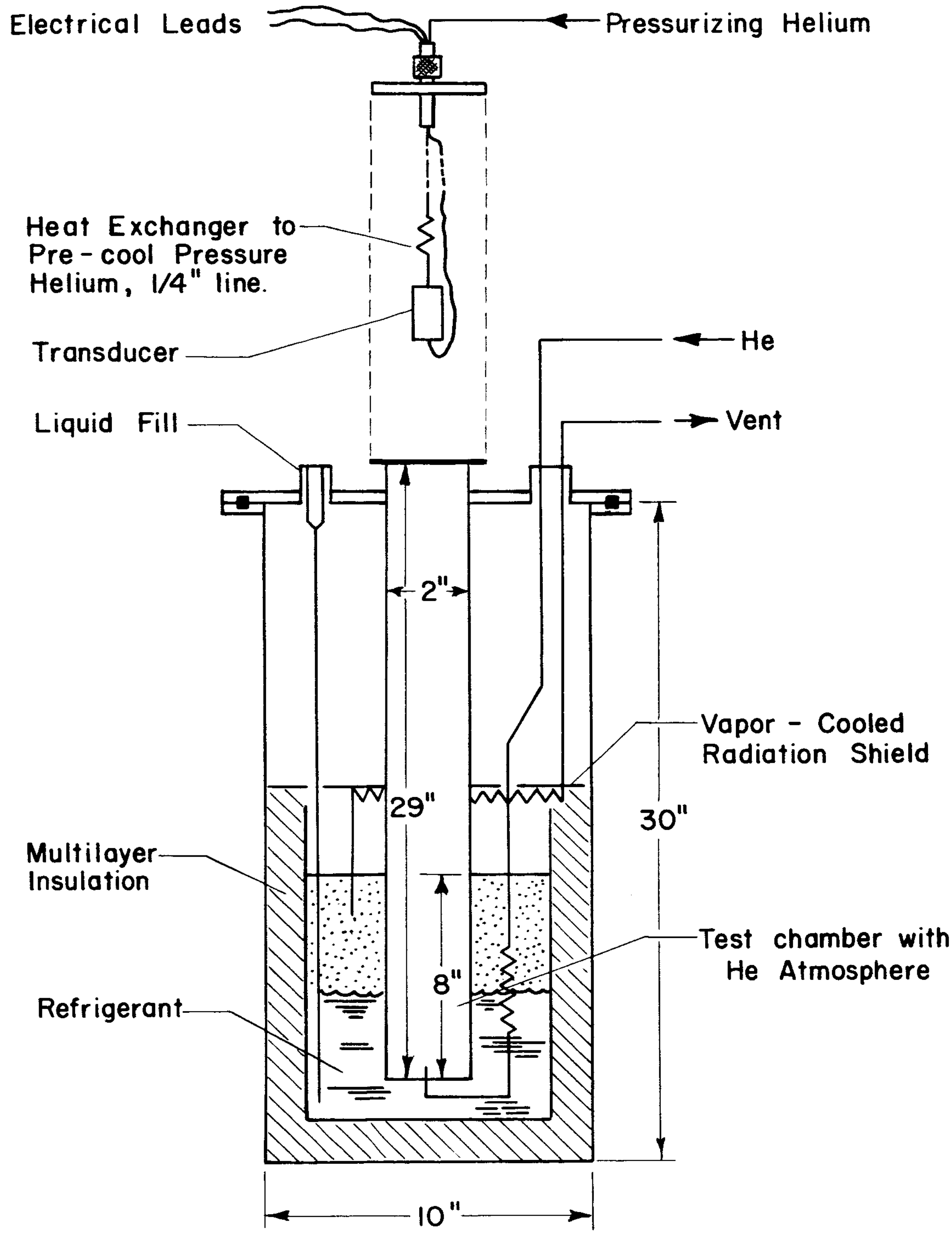

Figure 1. Cryostat for low temperature testing of pressure transducers.

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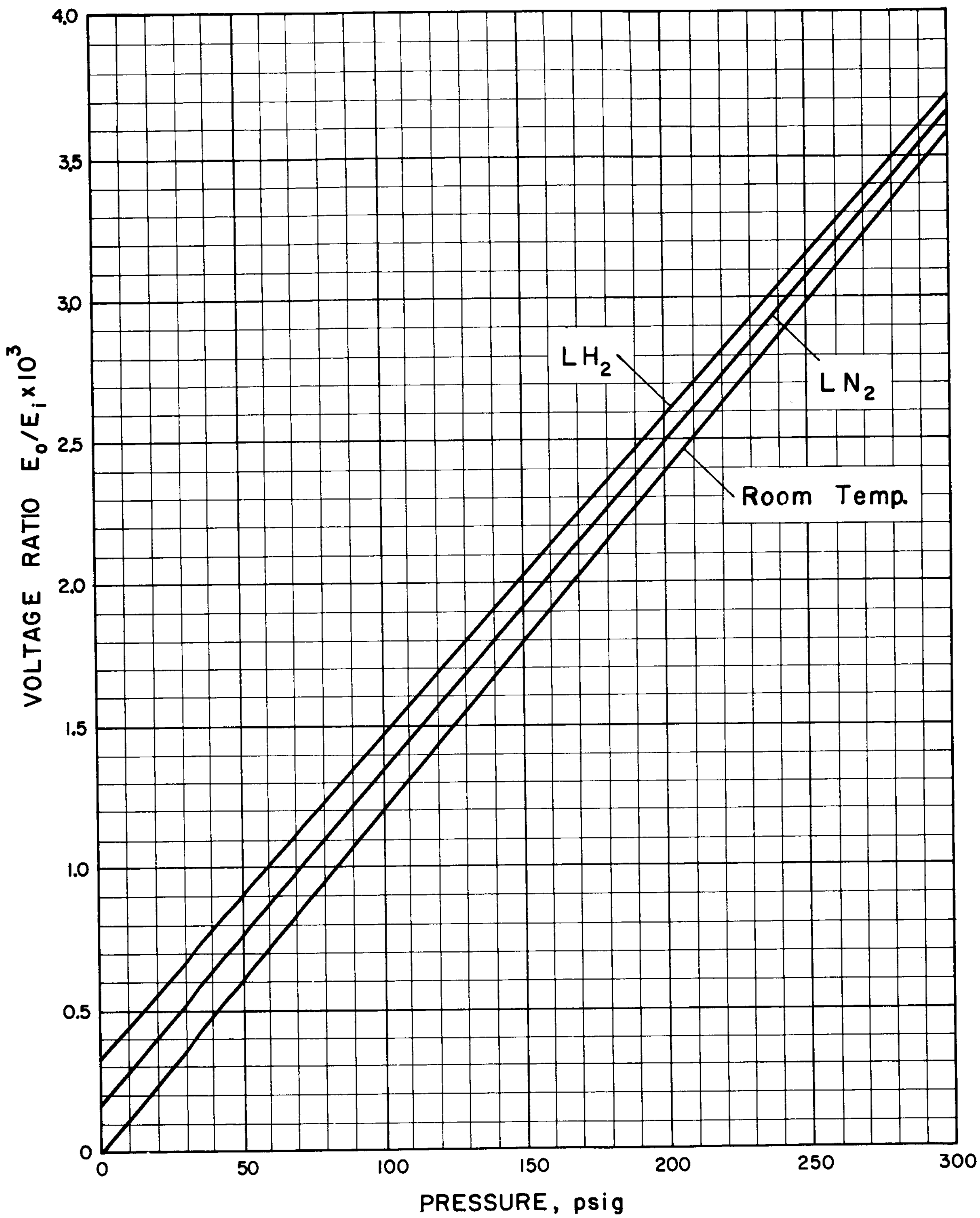

Figure 2. Bonded strain gage. Pressure range 0-300 psig.

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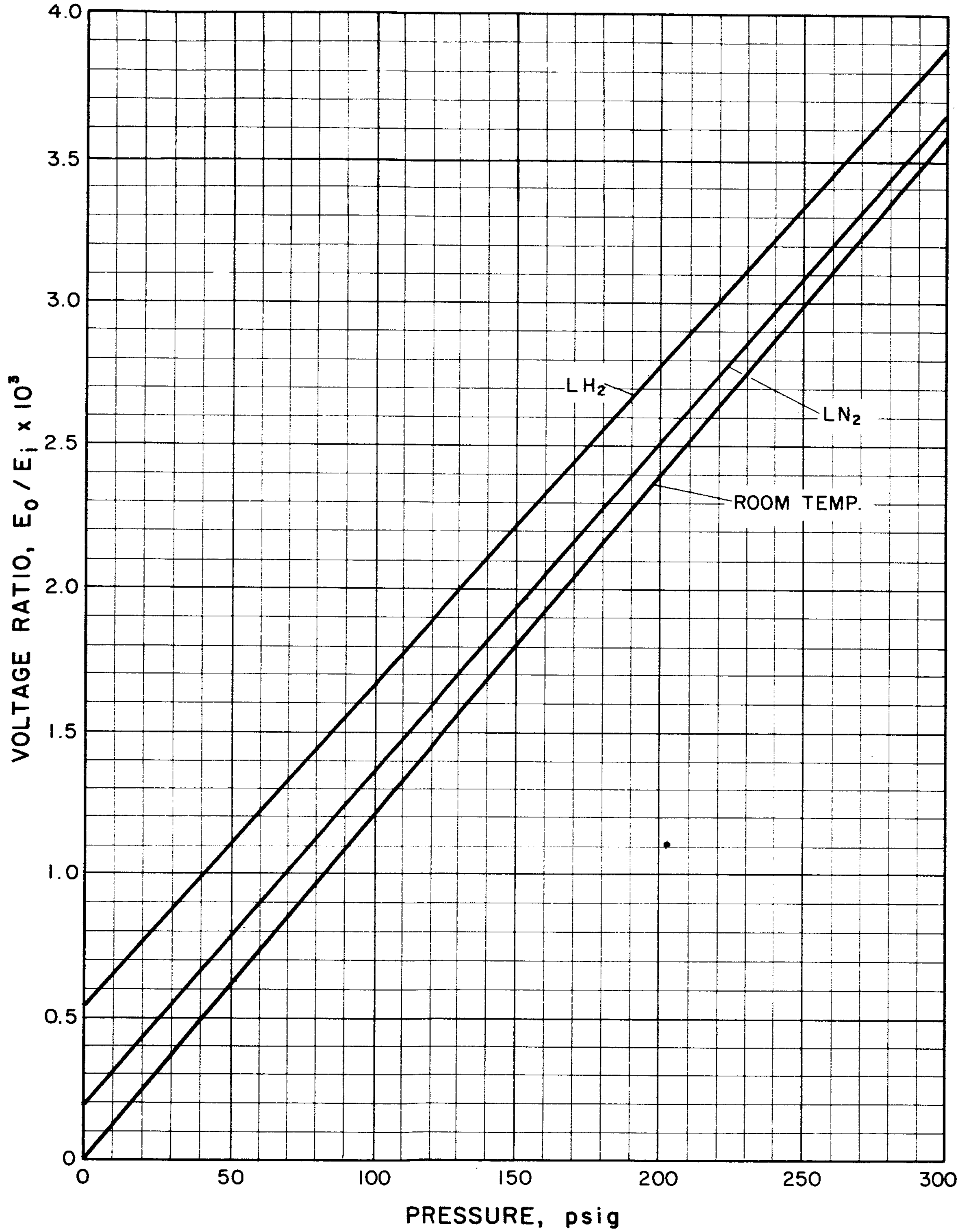

Figure 2a. Bonded strain gage. Pressure range 0-300 psig. After thermal cycling.

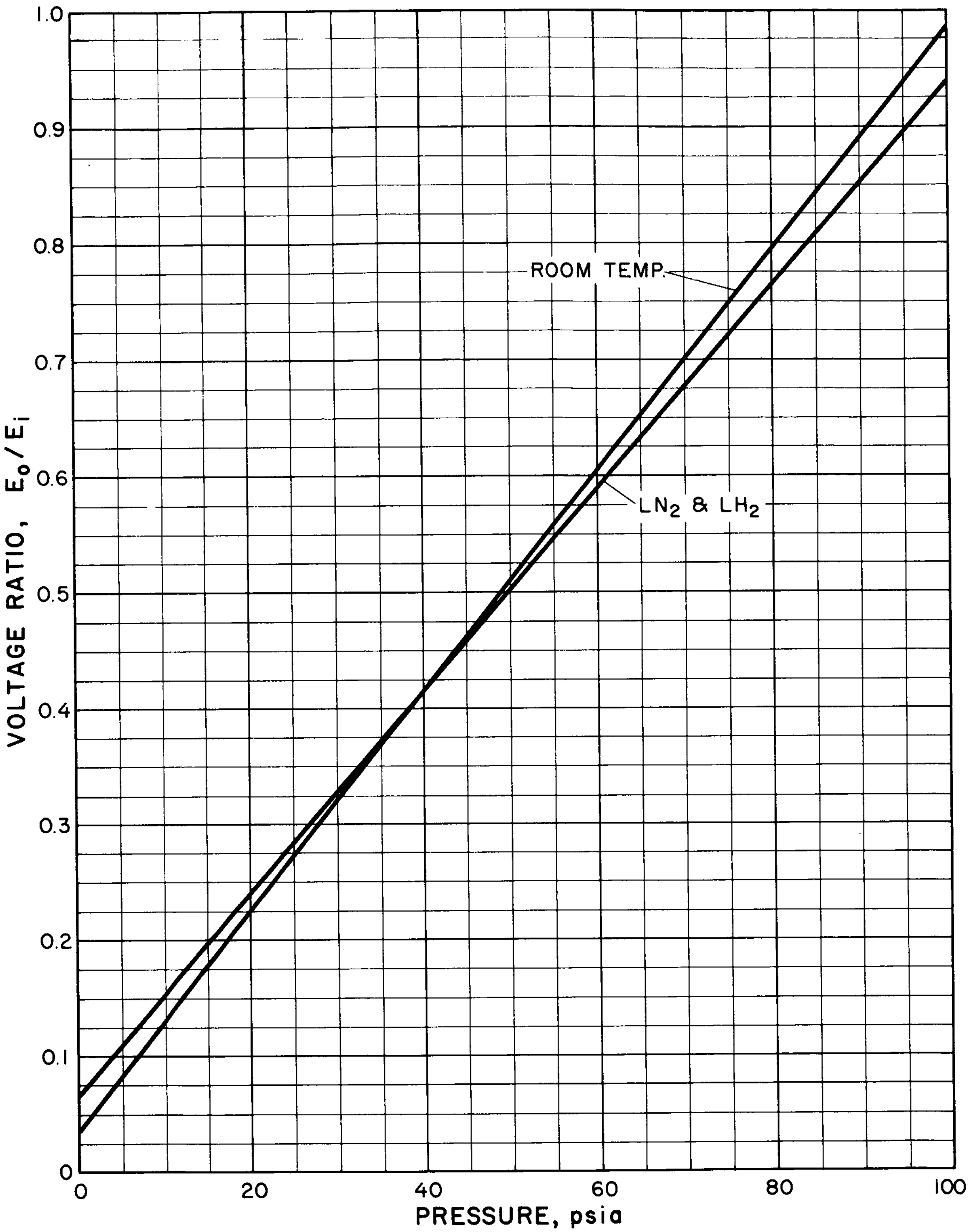

Figure 3. Potentiometer Type A. Pressure range 0-100 psia.

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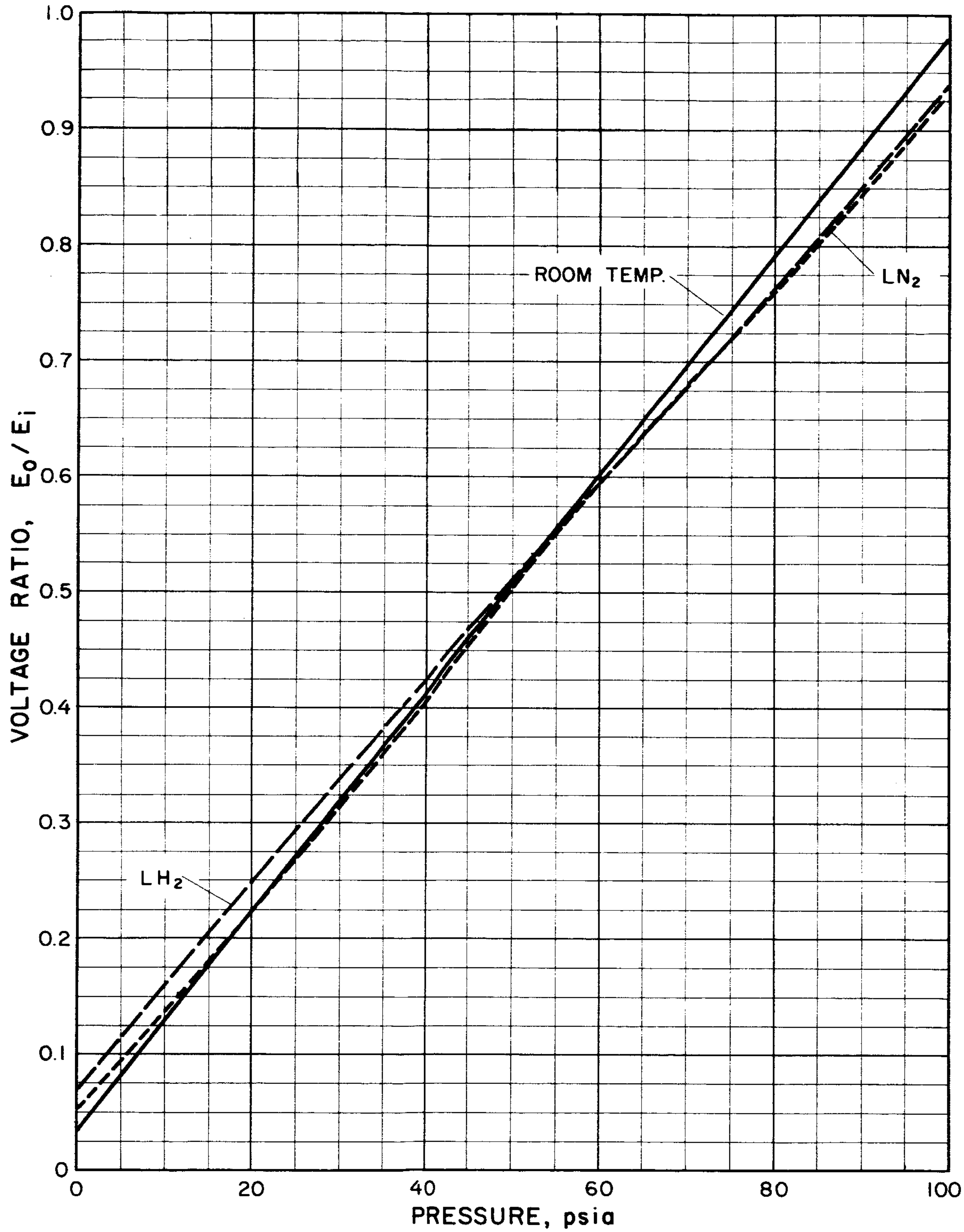

Figure 3a. Potentiometer Type A. Pressure range 0-100 psia.
After thermal cycling.

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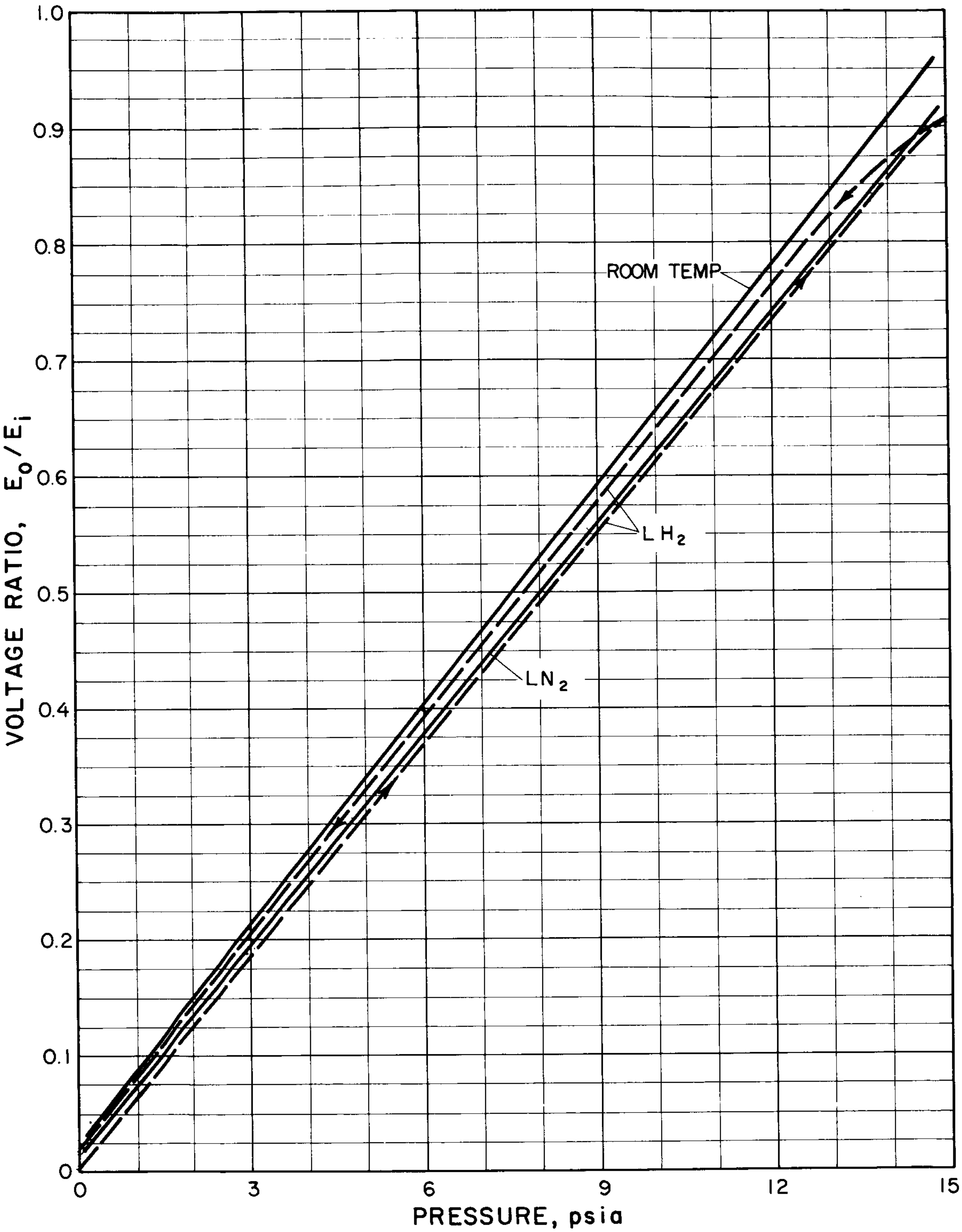

Figure 4. Potentiometer Type B. Pressure range 0-15 psia.

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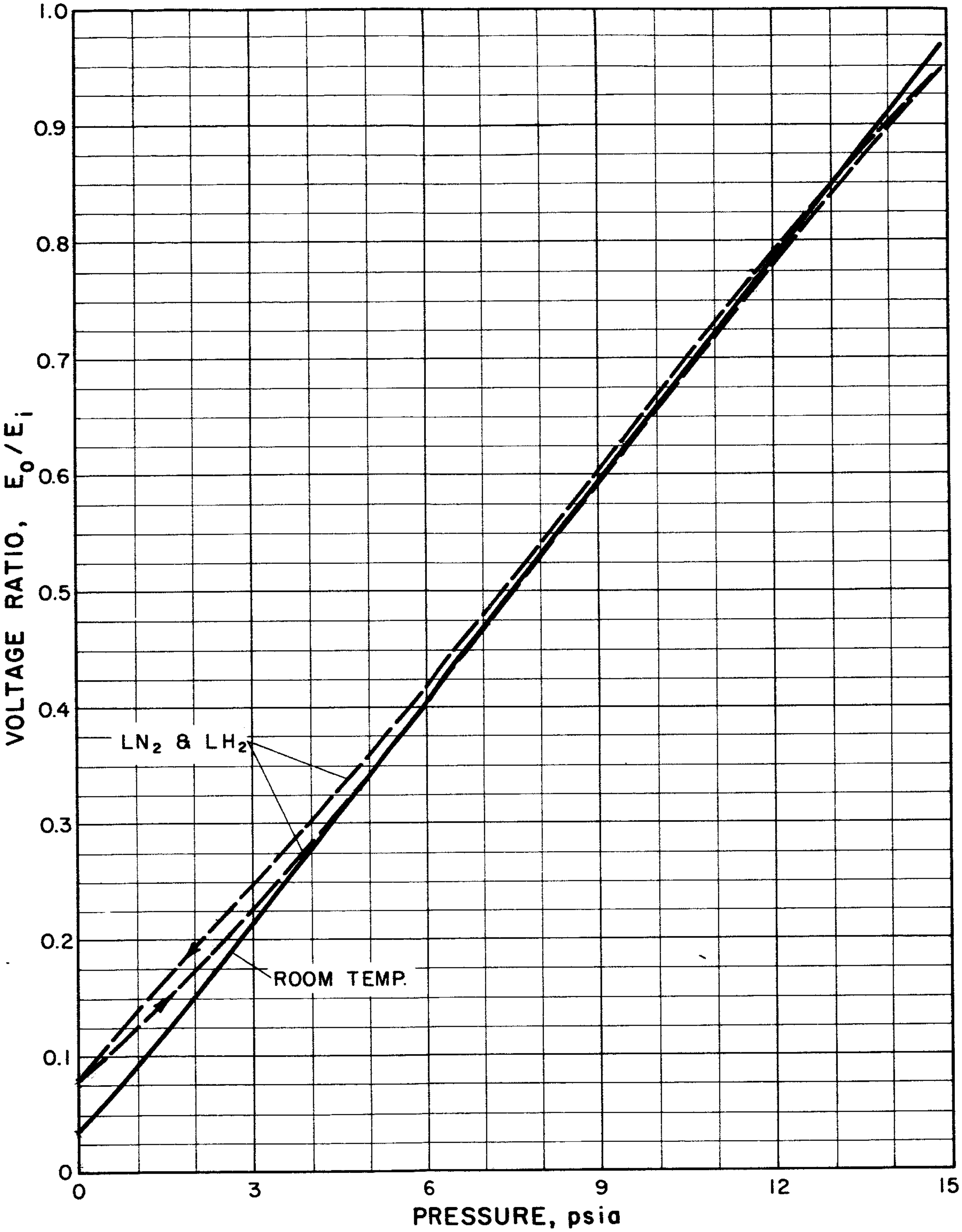

Figure 4a. Potentiometer Type B. Pressure range 0-15 psia. After thermal cycling.

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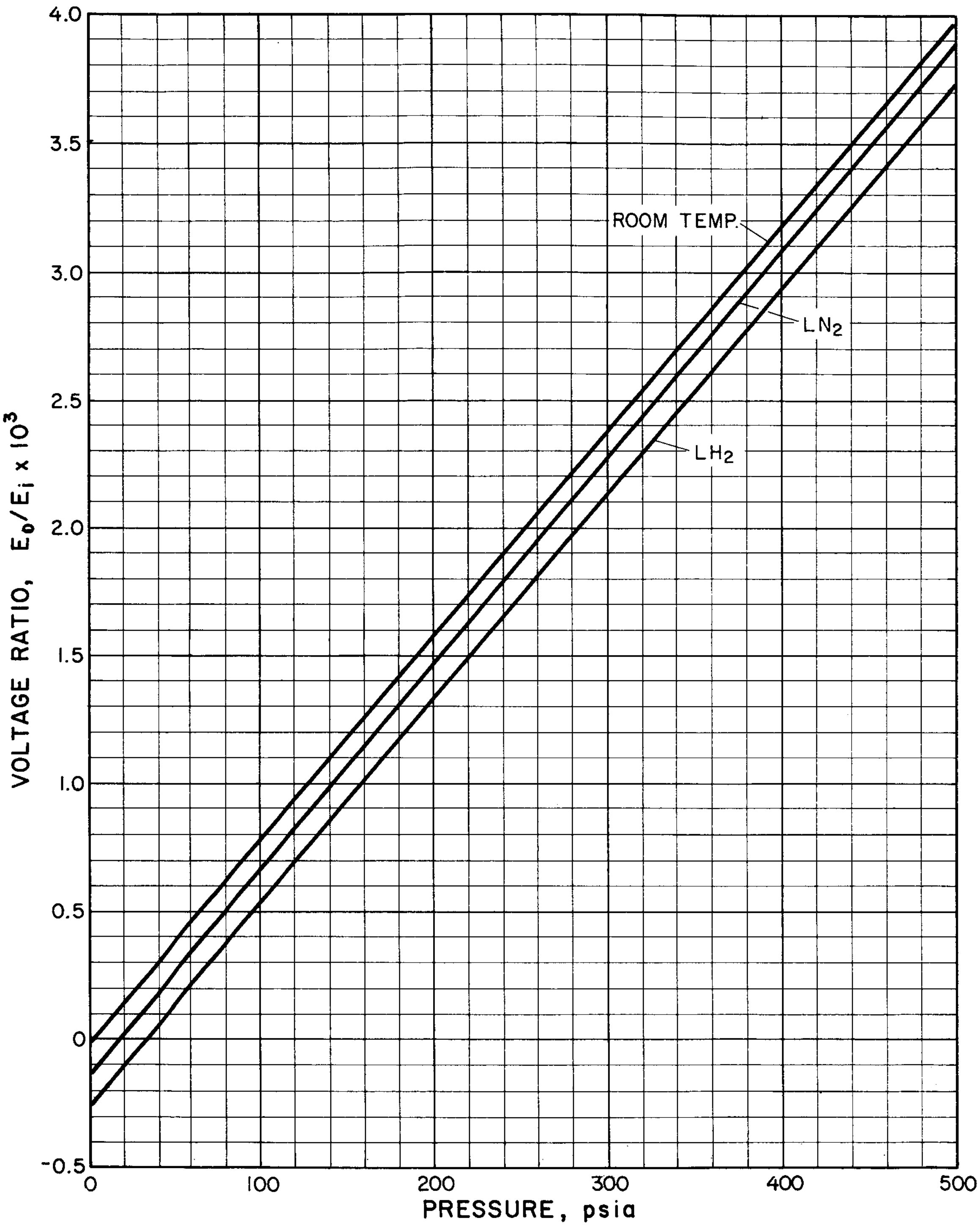

Figure 5. Unbonded strain gage Type A. Pressure range 0-500 psia.

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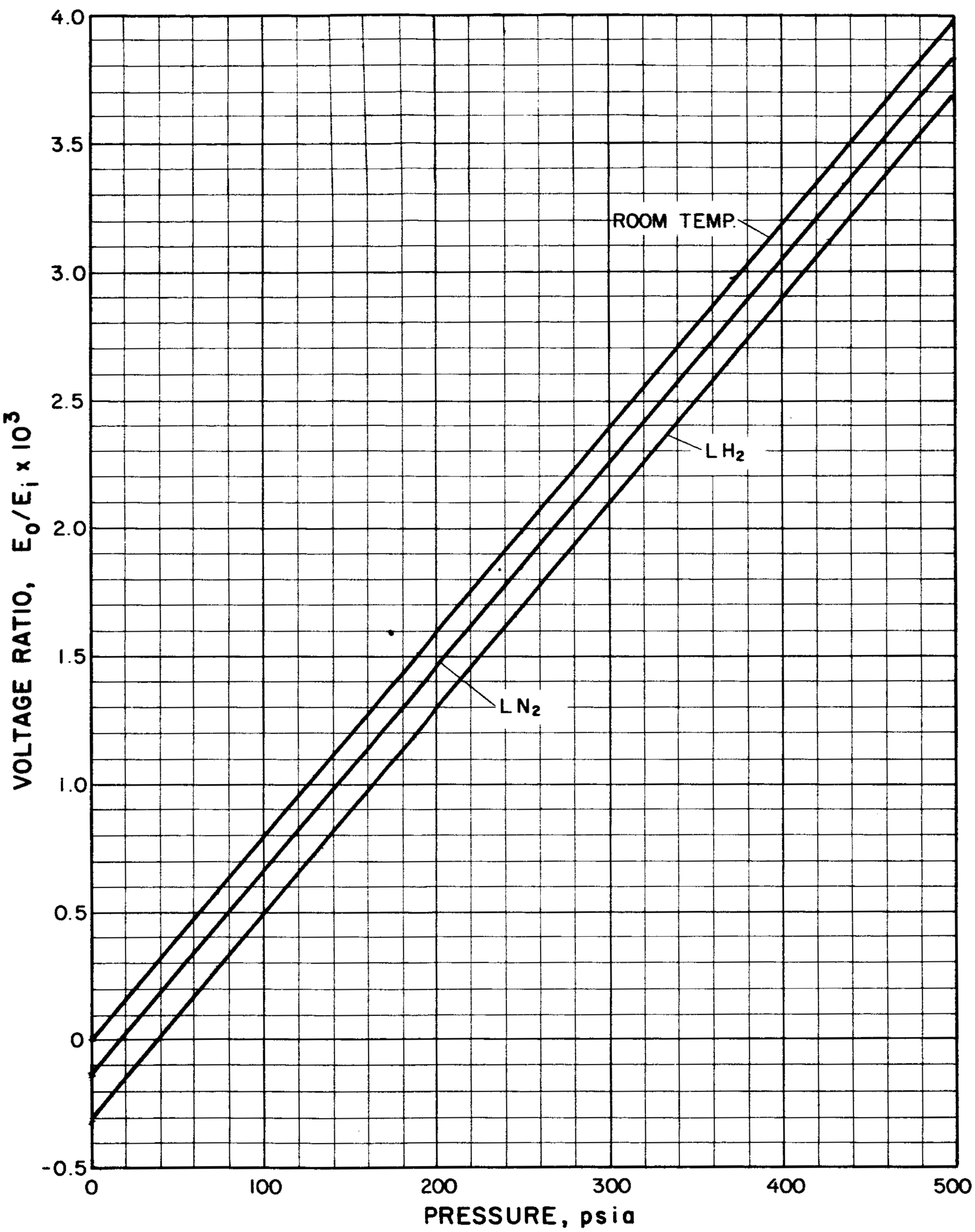

Figure 5a. Unbonded strain gage Type A. Pressure range 0-500 psia.

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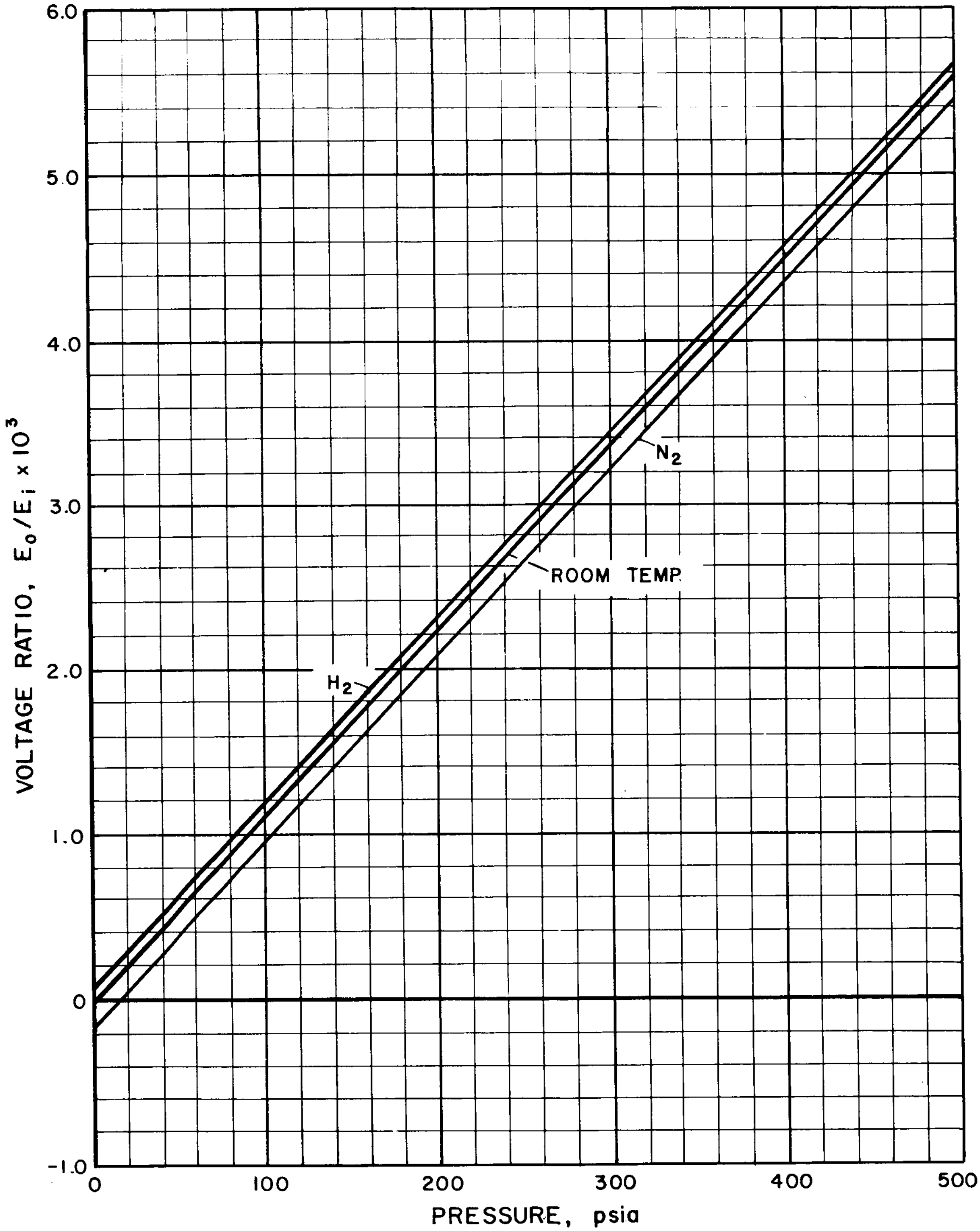

Figure 6. Unbonded strain gage Type B. Pressure range 0-500 psia.

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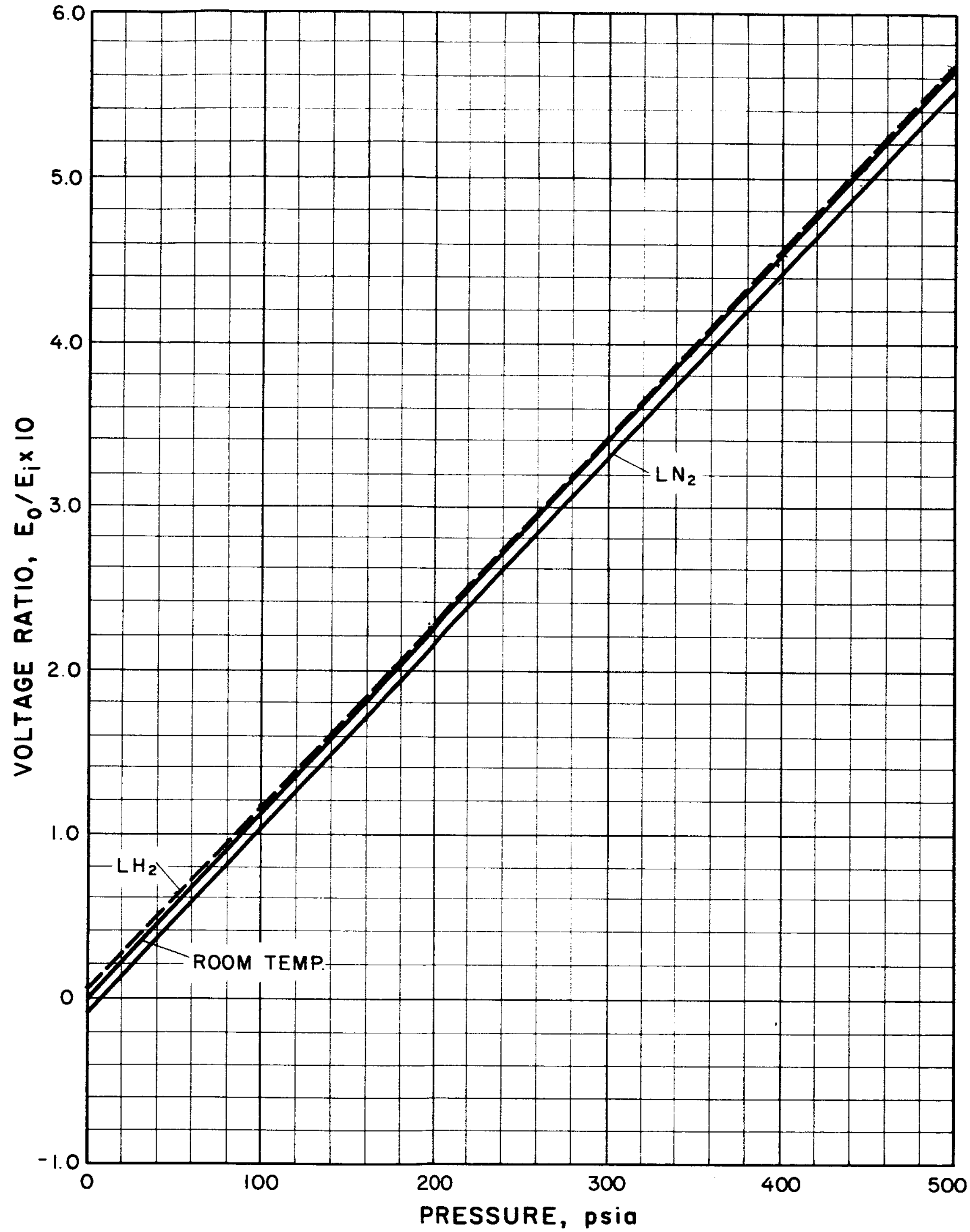

Figure 6a. Unbonded strain gage Type B. Pressure range 0-500 psia. After thermal cycling.

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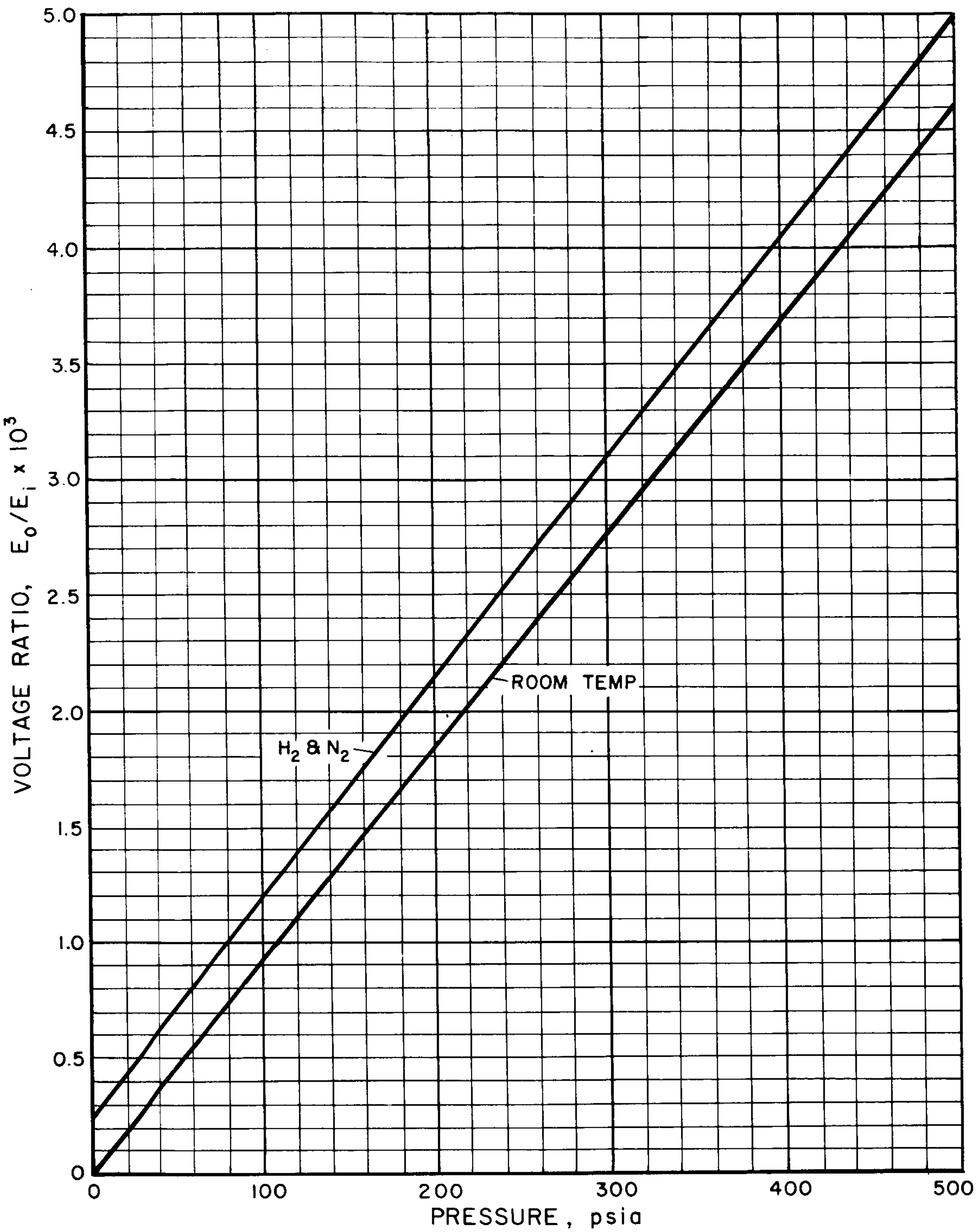

Figure 7. Unbonded strain gage Type C. Pressure range 0-500 psia.

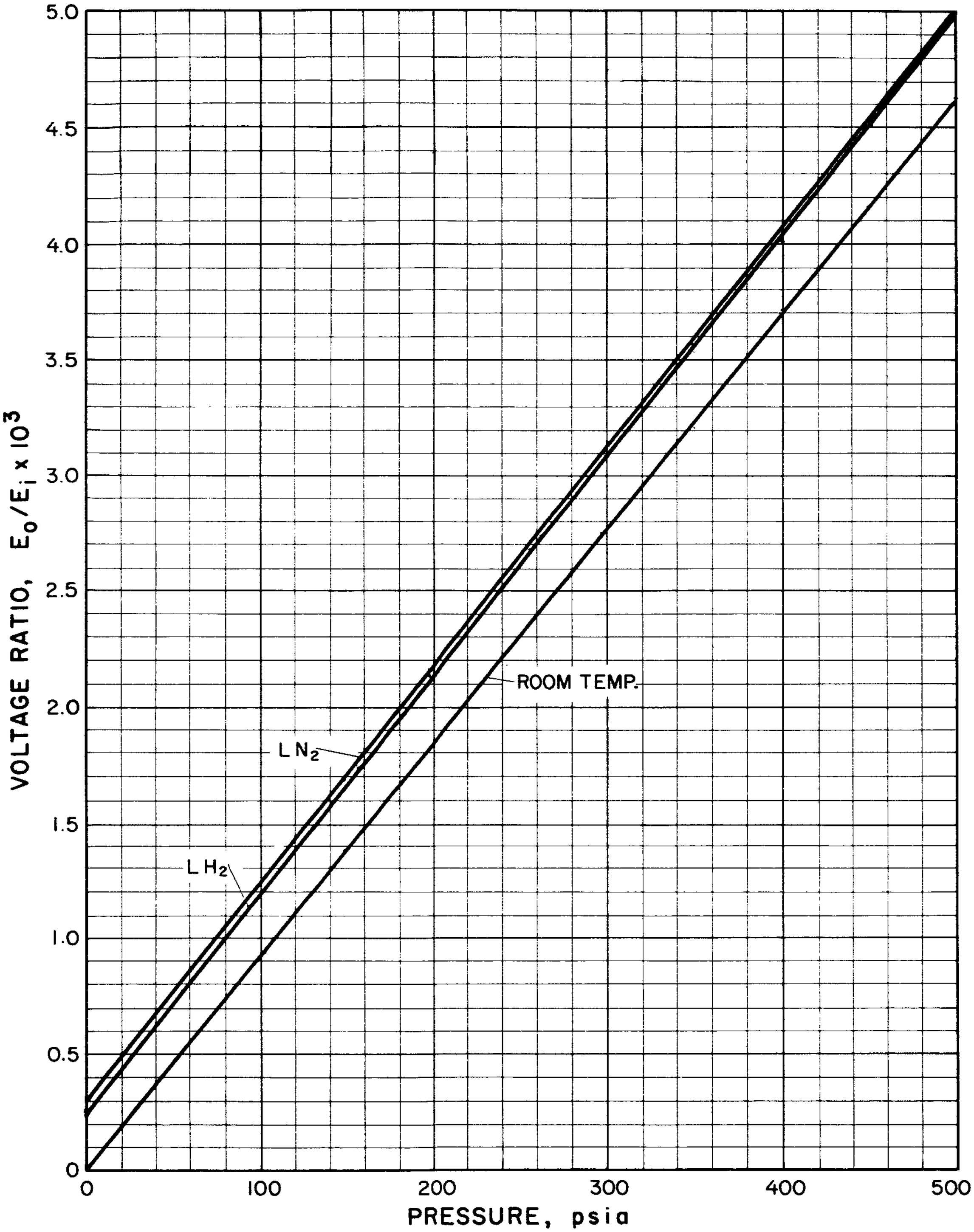

Figure 7a. Unbonded strain gage Type C. Pressure range 0-500 psia. After thermal cycling.

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